# Techniques for On-orbit Spatial Characterization of IKONOS

## HIGH SPATIAL RESOLUTION
## COMMERCIAL IMAGERY WORKSHOP
## GREENBELT, MARYLAND

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# Techniques for On-orbit Spatial Characterization of IKONOS

Outline

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- Experimental Procedures
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SOUTH DAKOTA STATE UNIVERSITY

# Background

- Modulation Transfer function (MTF)
  - A method of evaluating the spatial resolution of an imaging system.
  - NASA Science Data Purchase specifies MTF at Nyquist (0.1 for Pan band, 0.23 for Multispectral bands).
  - MTF is a measure of the spatial frequency response of an imaging system.
  - MTF is often calculated from the point spread function (PSF).

# Background (con't).

$$H(\omega_x, \omega_y) = \Im\{PSF(x, y)\}$$

$$MTF(\omega_x, \omega_y) = \frac{|H(\omega_x, \omega_y)|}{|H(0,0)|}$$

Often 1 dimensional functions are used:

–1-D PSF is the line spread function (LSF).

–LSF can be obtained by differentiation of the edge spread function (ESF).

- Pulse input analysis
  - A pulse input is presented to an imaging system.
  - Output of the system is the resultant image.
  - Fourier transform the input and output.
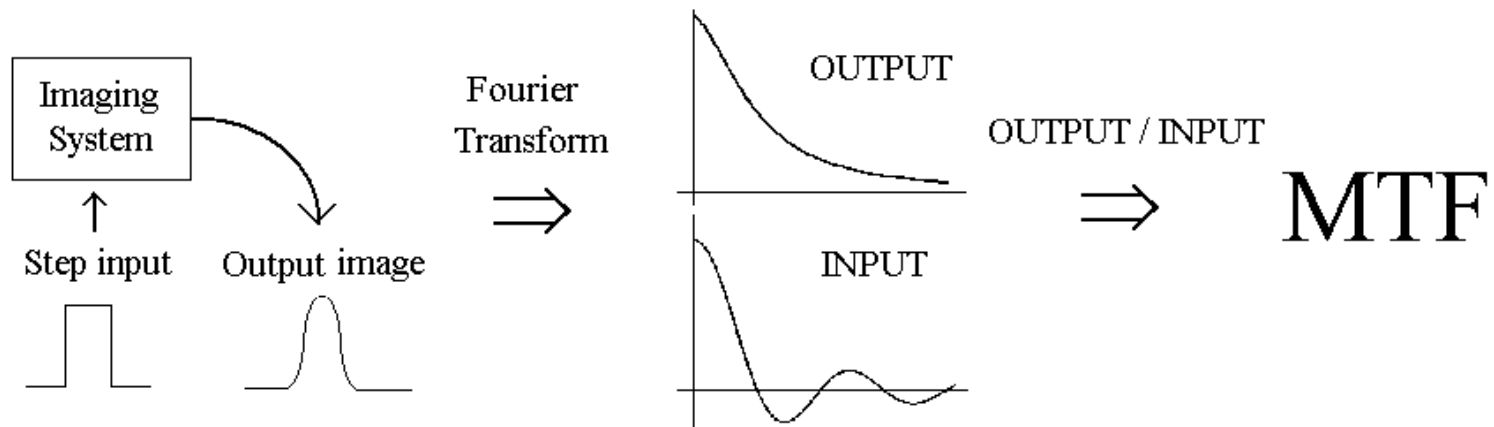  - MTF is calculated by dividing output by input and normalizing.

Fig 1. Pulse input analysis

- Edge input analysis
  - A knife edge should be chosen in an image.
  - Average the profile along the edge point (ESF).
  - Differentiate the averaged profile.
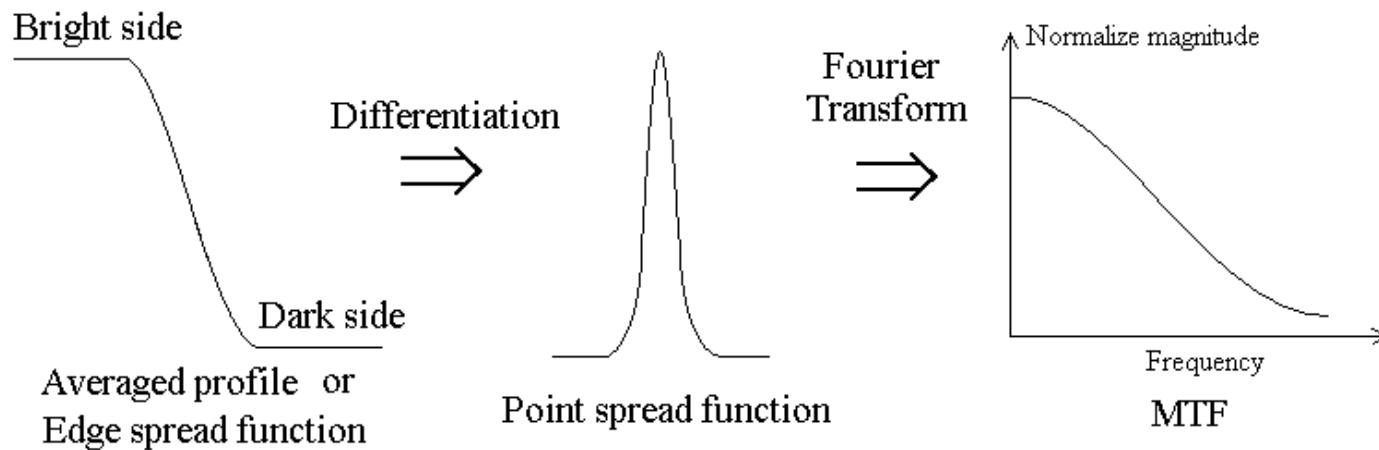  - Fourier transform and normalize.

Bright side

Differentiation
$\Rightarrow$

Fourier
Transform
$\Rightarrow$

Normalize magnitude

Dark side

Averaged profile or
Edge spread function

Point spread function

Frequency

MTF

Fig 2. Edge analysis

# Objective

- Measure edge and pulse response of imaged targets.
- Estimate PSF & MTF of IKONOS system from satellite images.
- Obtain MTF at Nyquist frequency in Pan and Multispectral bands.
- Compare on-orbit estimated MTF at Nyquist with NASA IKONOS SDB specifications.

# Experimental Procedures

- Three techniques were developed:

  Tarps were deployed for a pulse input.

  Existing Parking Lots were used for edge inputs.

  Runway Centerlines were used for pulse input.

- Two Data Collection Events occurred:

  ➢ May 1, 2000

  ➢ June 30, 2000

# Experimental Procedures

- Tarps
  - A uniform grassy field was chosen for a homogeneous background.
  - 6 blue tarps (3 x 30 m) were laid out in a 2 by 3 pattern covering 9m by 60m.
  - Tarp edges were aligned by surveyor's transit.
  - The 60m edges were aligned $8^o$ E of true north to optimize phasing of pixels along the edge.
  - Pulse input method was applied for Multispectral bands.
  - Edge input method was applied for Pan-band.
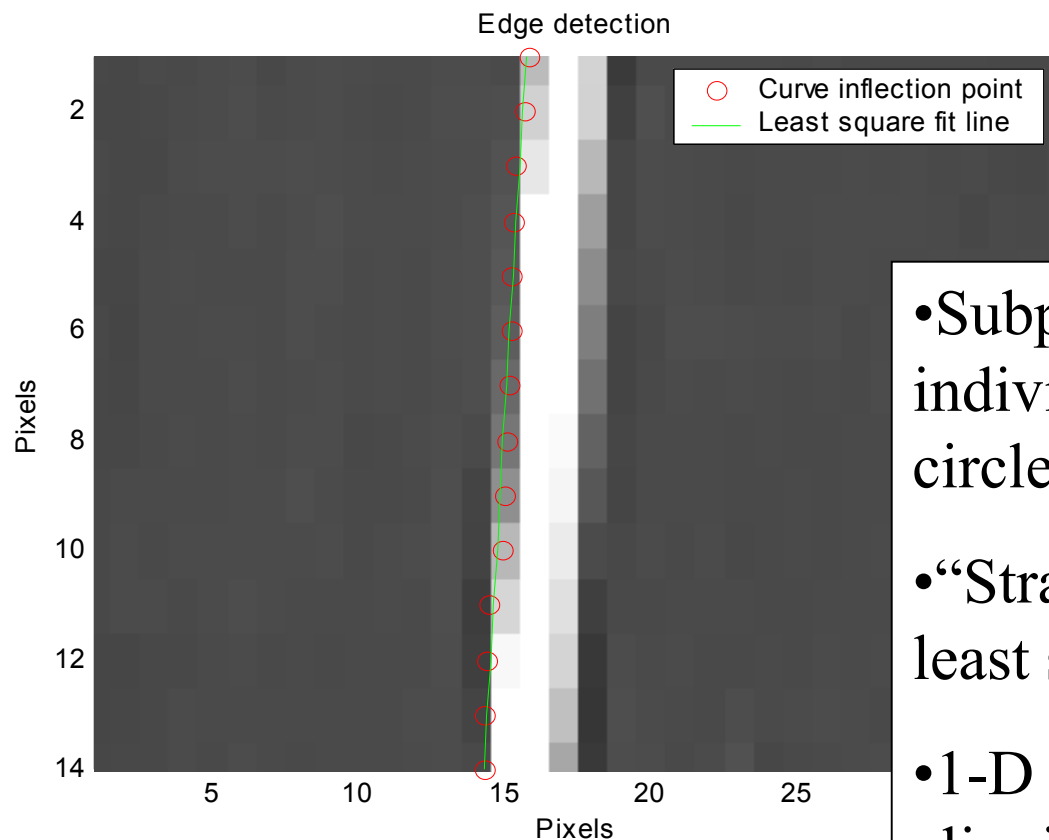
(a) Panchromatic band          (b) RGB Multispectral bands

Fig 3. IKONOS Image of tarps on June 30 2000.

# Process to determine subpixel resolution:

- Find adjacent pixels with largest difference

- Fit cubic polynomial to four pixels surrounding largest difference.

- Declare edge location as inflection point of cubic function.

Edge Location

X
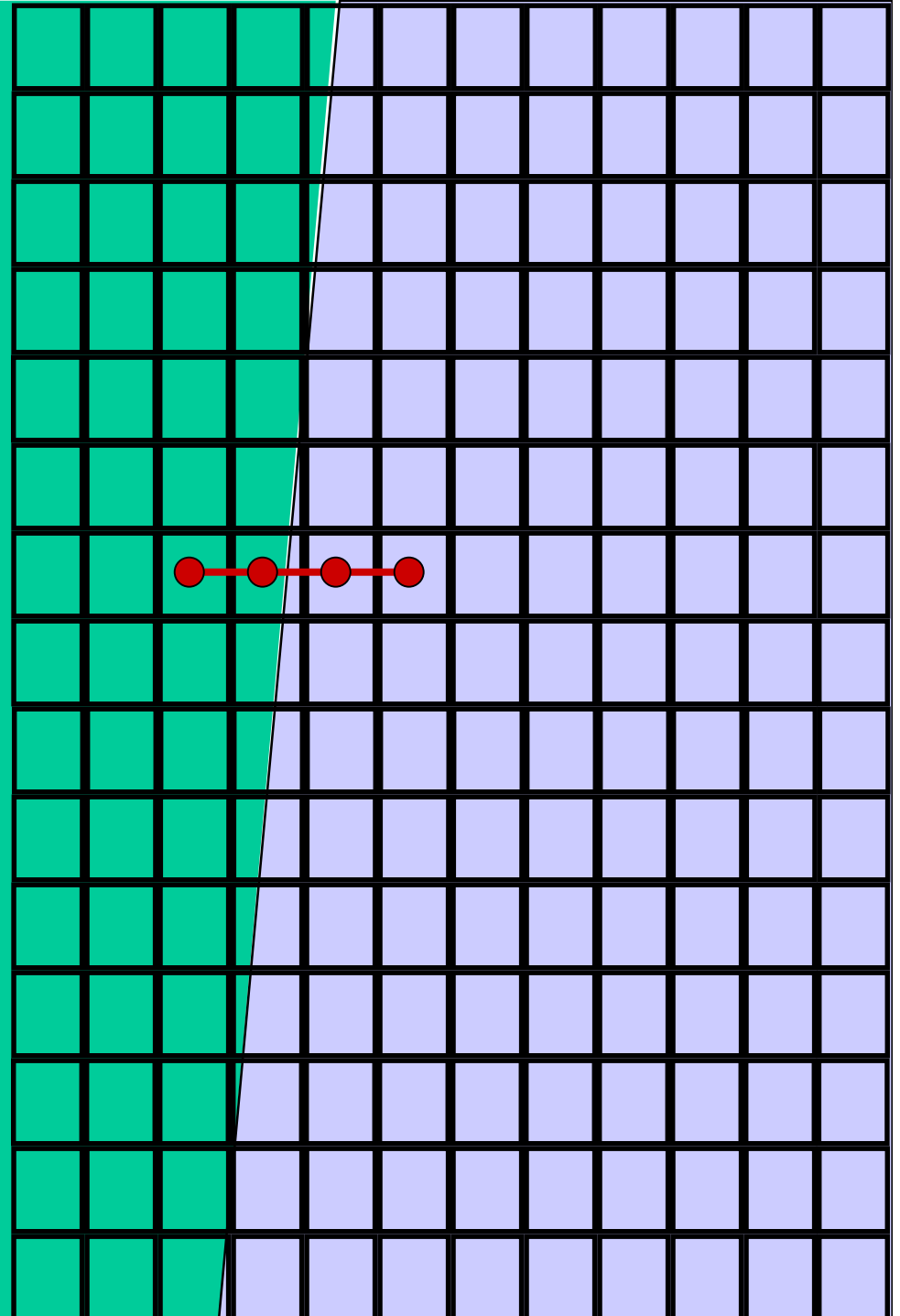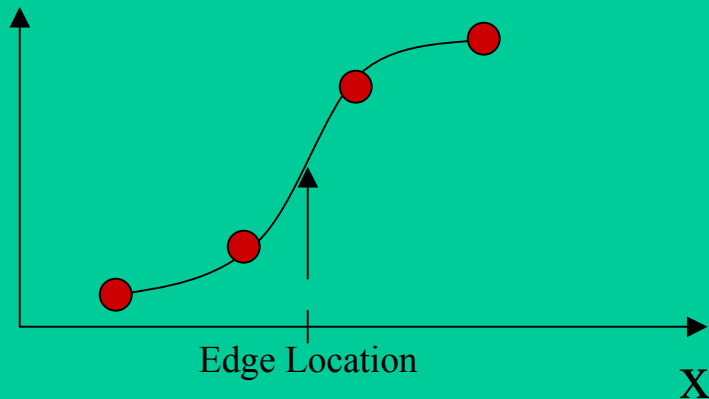
# Development of Edge Profile



- Subpixel edge location for individual scan indicated by red circle

- "Straight Edge" indicated by least squares line in green.

- 1-D edge profile built-up by aligning individual scans.

# Development of average target response

- Edge locations were calculated in Figure 4.
- Aligned edges shown as red data points in Figure 5.
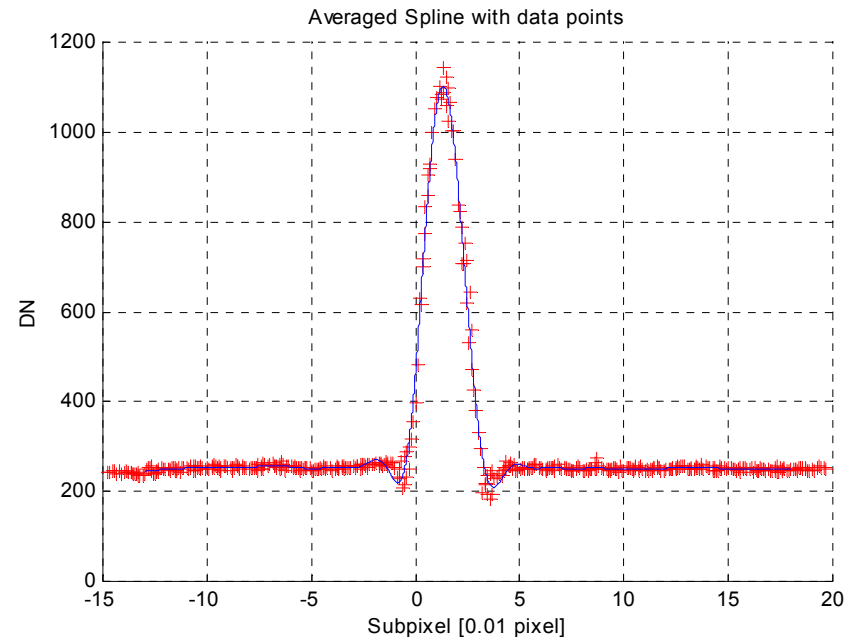- Average profile (in blue) was calculated using cubic splines as in Figure 5. *No analytical model used.*
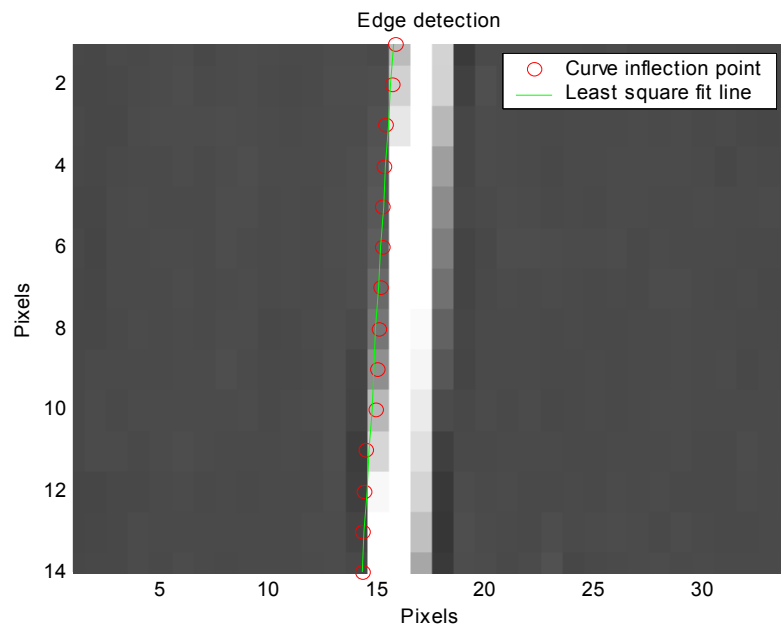


Figure 4. Edge detection



Figure 5. Average profile

# Pulse Response Technique

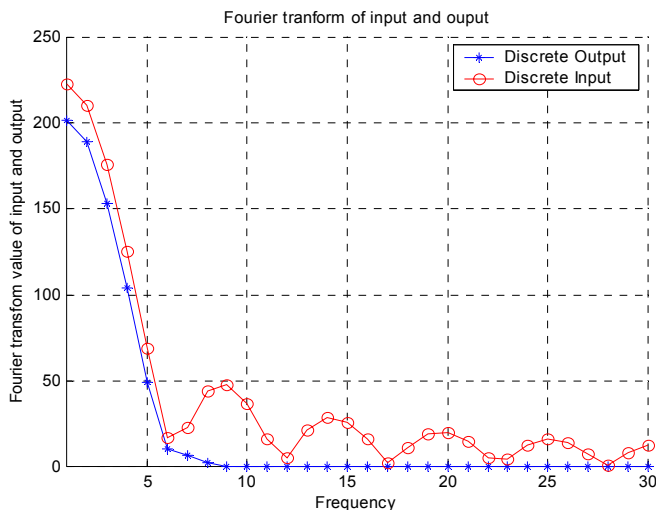- Consider horizontal cross-section as a pulse input.

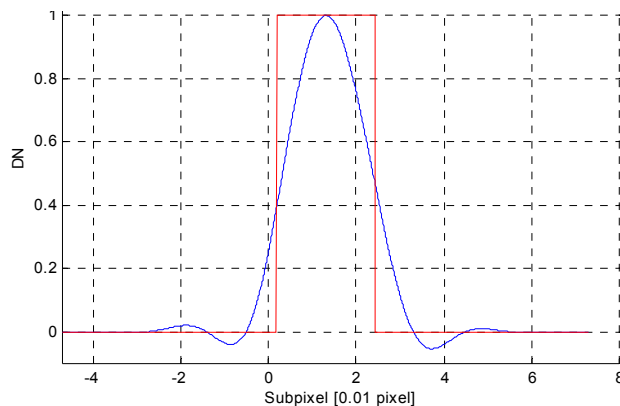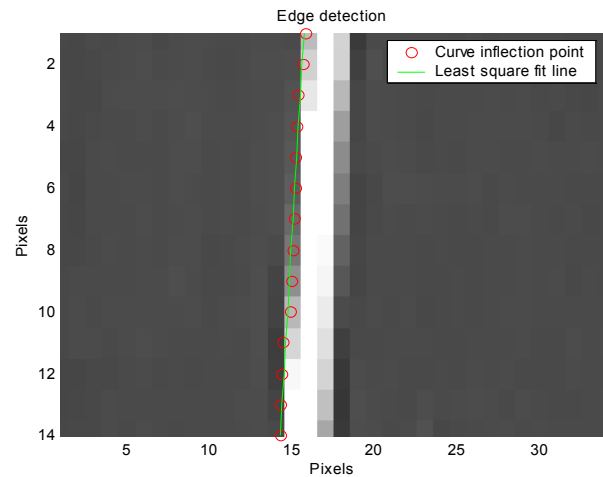- Generate pulse input in pixel space.

- Generate pulse response profile.

- Fourier transform input and output
  - Analytical form (or FFT)for input.
  - FFT for response.

- Pulse Method Technique (Cont.)
  - Normalized Fourier transform of output divided by input yields MTF.
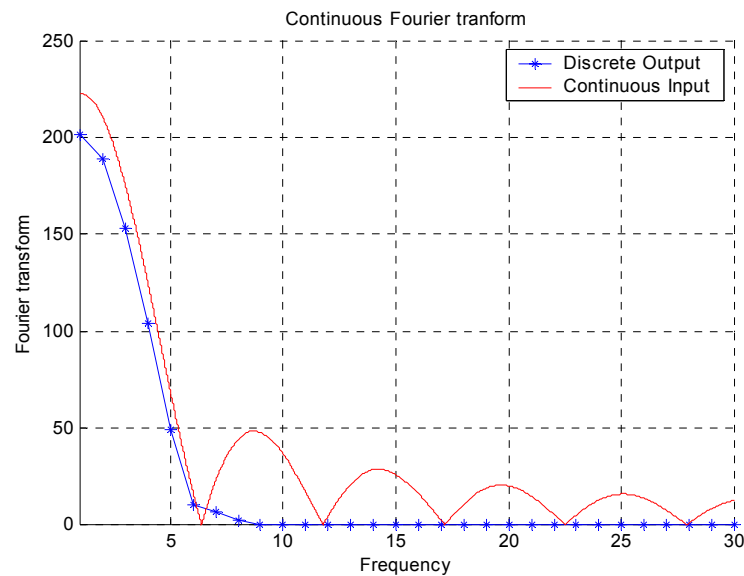  - MTF is shown in Figure 9.
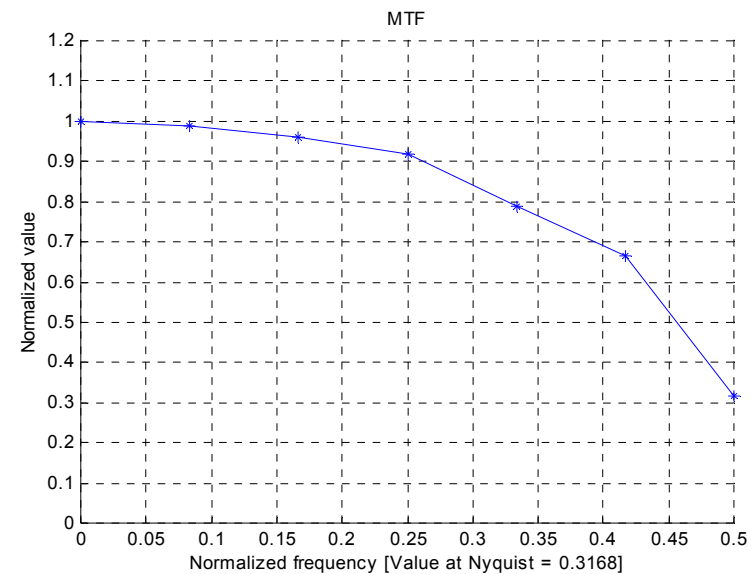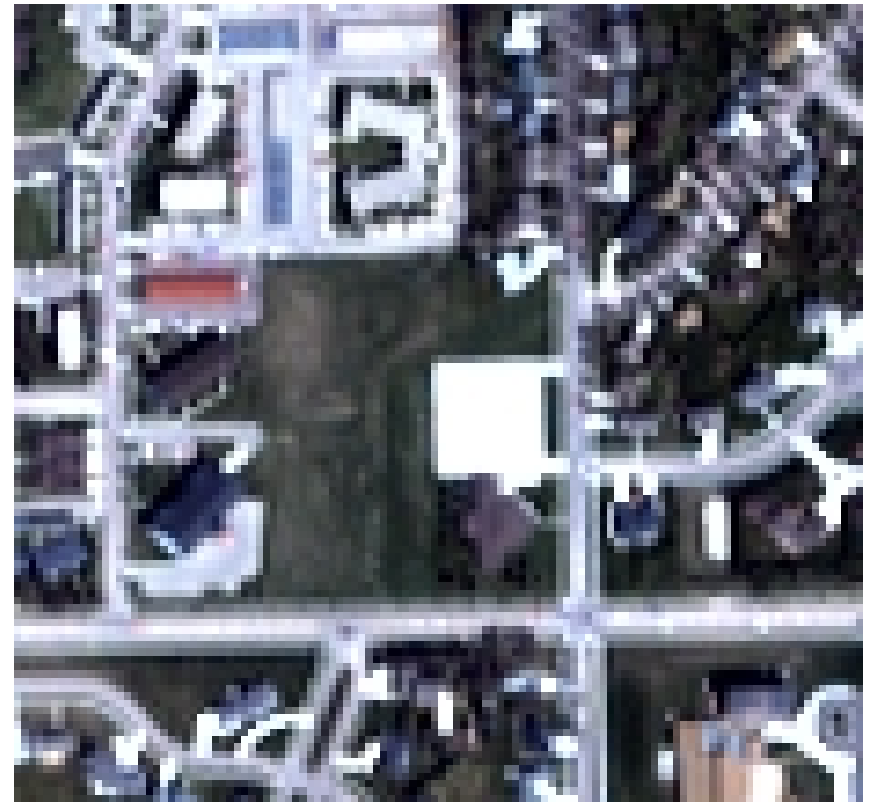


Figure 8. Input verification

Figure 9. MTF

# Edge Response Technique

– Two uniform bright regions (parking lots) with uniform adjacent dark regions (grass) were identified.

– Orientation of edge was close to true north.

– Edge input method was applied for Pan, red, green and blue band analysis.  No edge existed for NIR band.
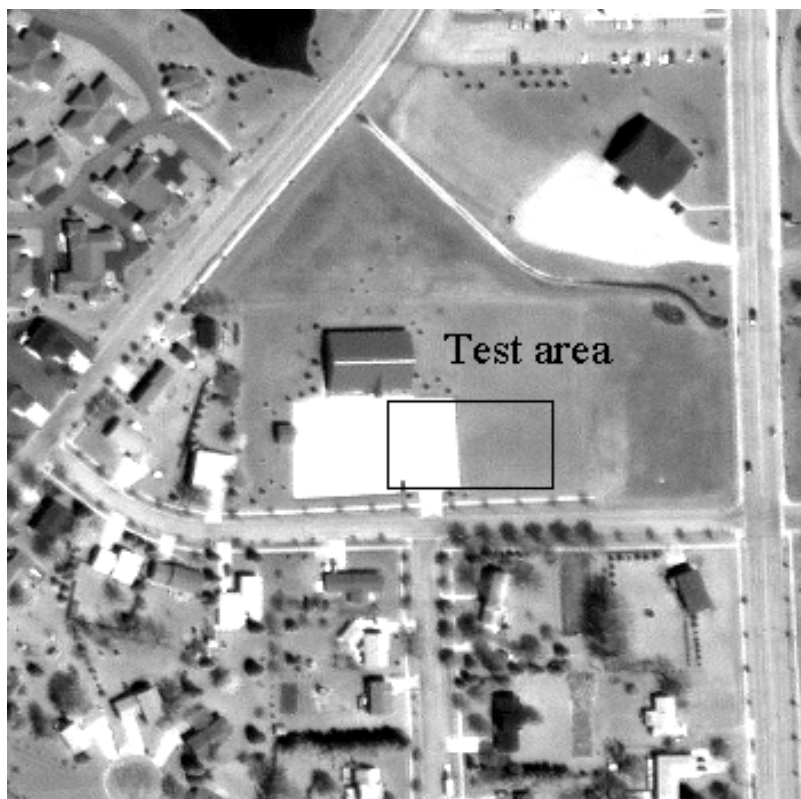
(a) Panchromatic band (b) RGB Multispectral bands

Figure 10. Parking lot 1 on May 1 2000.

(a) Panchromatic band      (b) RGB Multispectral bands

Figure 11. Parking lot 2 on May 1 2000.

- Edge method procedures
  - Edges locations were calculated as before.
  - Aligned edge profile shown as red points in Figure 13.
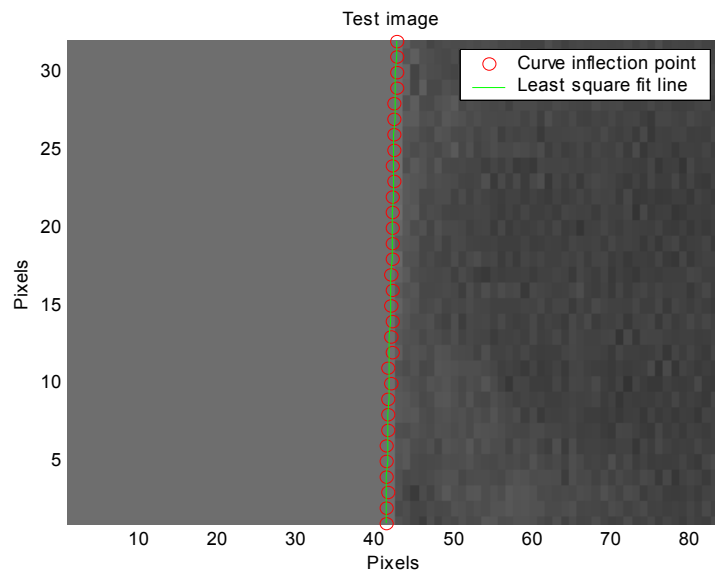  - Cubic splines used to obtain average edge profile.
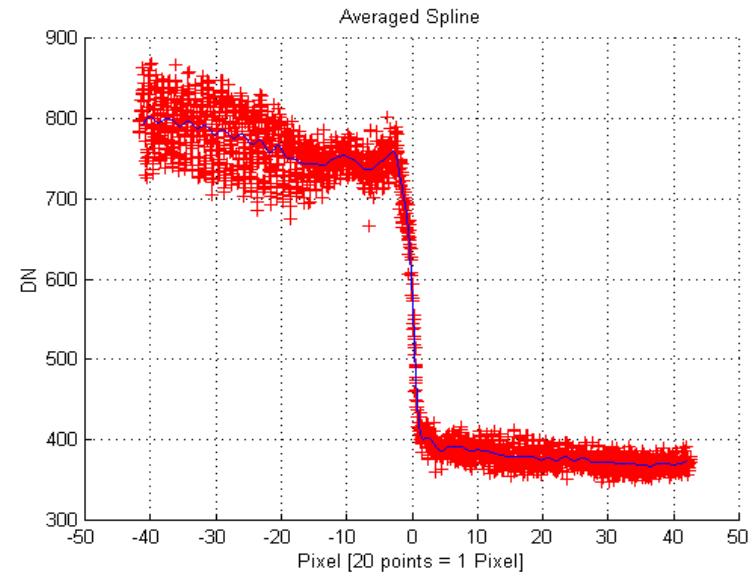


Figure 12. Edge detection



Figure 13. Average profile

- Edge method procedures (Cont.)
  - Digital differentiation applied to averaged profile shown in Figure 14.
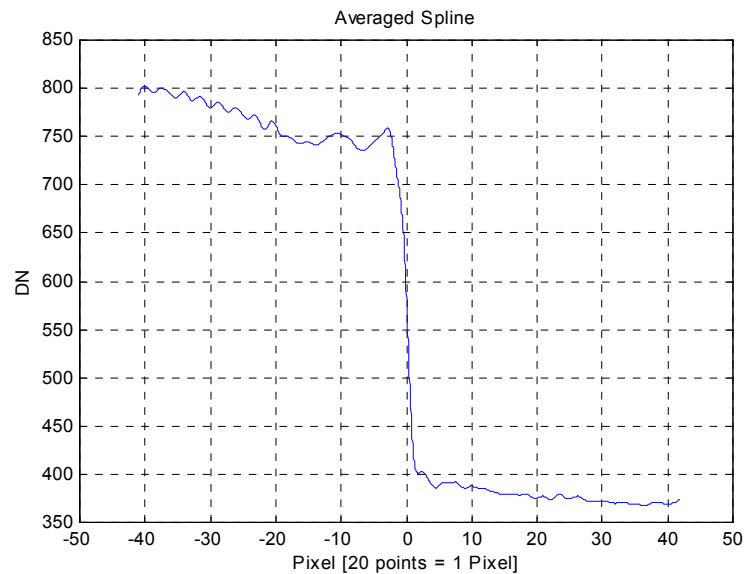  - Line spread function (LSF) by differentiation is shown in Figure 15.
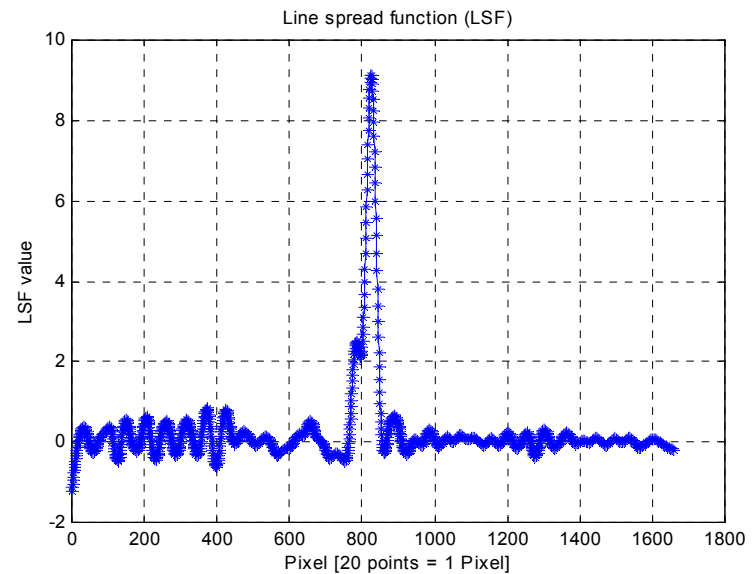
Figure 14. Averaged profile

Figure 15. Average profile

- Edge method procedures (Cont.)
  - LSF was trimmed by the edge location in Figure 16.
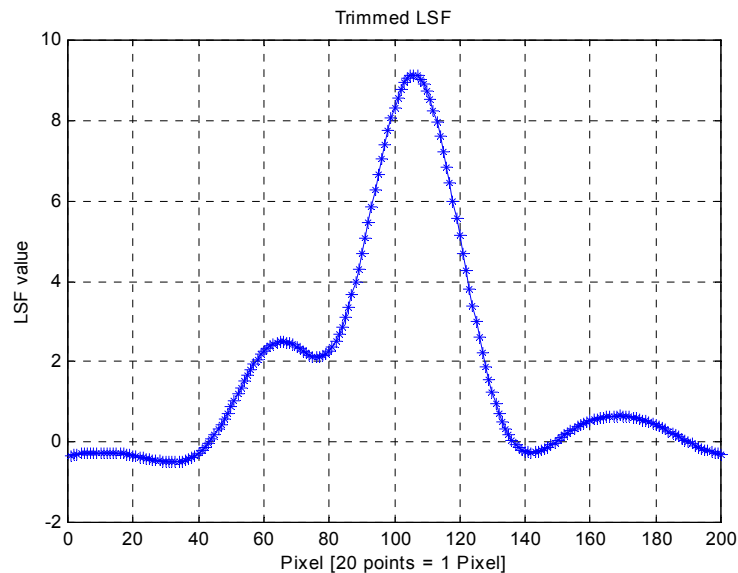  - MTF was calculated by taking Fourier Transform in Figure 17.
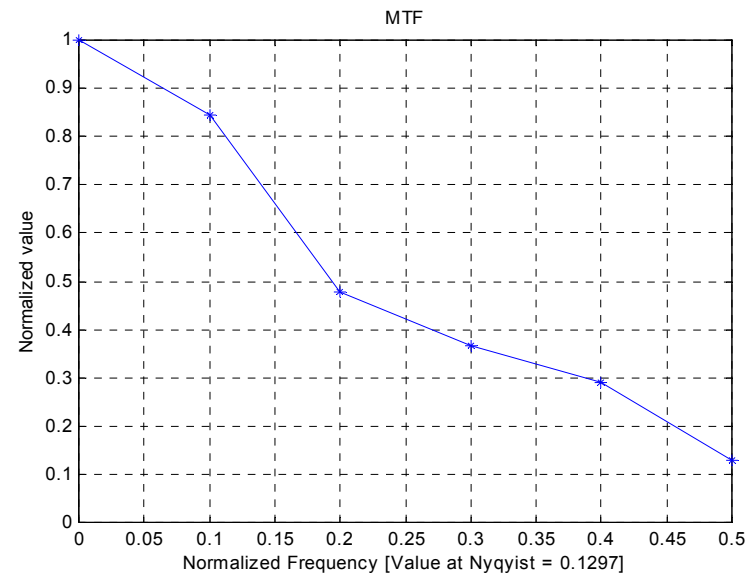
Figure 16. Trimmed LSF

Figure 17. MTF

# Airport Centerline Technique

- Airport runway had uniform dark background.
- Center lines formed a bright pulse input.
- Runway sections were chosen by the presence of center lines (and absence of taxi lines) in Figure 18.
- Pulse input method was applied for Pan-band analysis (width of centerline was approx. 1meter).

Figure 18. Airport center lines on June 30 2000.

# Results

- ## Brookings Area
  - ### Multi-spectral band analysis
    - Standard products with / without MTFC on June 30 2000 were used.
    - A Precision product without MTFC on June 30 2000 was also analyzed.
    - Pulse responses of tarps and MTF result plots are shown in following Figures.

# Table 1. DN levels

| Area / Date | Product type | Targets | DN levels with 1 -σ error bound | | | | | | | | | |
| | | | Pan-band | | Blue | | Green | | Red | | NIR | |
| | | | Bright | Dark | Bright | Dark | Bright | Dark | Bright | Dark | Bright | Dark |
| Brookings May 1 2000 | Standard MTFC On | Tarps | 607±24 | 293±13 | 834 ±82 | 251±4 | 535 ±43 | 260 ±6 | 341±22 | 226±7 | 826±68 | 364±26 |
| | | Parking lot 1 | 656±34 | 371±17 | 556±20 | 243±10 | 730±32 | 265±16 | 689±33 | 205±23 | N/A | N/A |
| | | Parking lot 2 | 710±29 | 363±11 | 642±36 | 229±6 | 843±42 | 245±9 | 772±39 | 185±13 | N/A | N/A |
| | | Airport | 449±46 | 190±8 | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| Brookings June 30, 2000 | Standard MTFC On | Tarps | 749±38 | 366±12 | 949±149 | 251±5 | 673±82 | 287±8 | 442±51 | 226±12 | 975±94 | 561±21 |
| | | Parking lot 1 | 666±24 | 397±15 | 547±26 | 259±12 | 732±46 | 299±21 | 687±48 | 252±29 | N/A | N/A |
| | | Parking lot 2 | 769±37 | 377±12 | 662±51 | 237±3 | 886±55 | 265±5 | 815±47 | 211±7 | N/A | N/A |
| | | Airport | 423±47 | 177±7 | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| | Standard MTFC Off | Tarps | 747±30 | 366±9 | 891±125 | 251±4 | 636±73 | 287±7 | 421±41 | 226±11 | 927±71 | 563±18 |
| | | Parking lot 1 | 656±16 | 398±13 | 551±25 | 261±12 | 737±43 | 302±21 | 692±46 | 256±30 | N/A | N/A |
| | | Parking lot 2 | 765±33 | 377±9 | 649±42 | 238±3 | 863±52 | 267±5 | 791±48 | 212±7 | N/A | N/A |
| | | Airport | 359±26 | 177±4 | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| | Precision MTFC On | Tarps | 678±28 | 390±12 | 912±121 | 263±5 | 593±55 | 303±9 | 357±28 | 240±13 | 898±59 | 576±21 |
| | | Parking lot 1 | 677±22 | 408±17 | 570±11 | 264±6 | 767±19 | 301±12 | 723±20 | 249±18 | N/A | N/A |
| | | Parking lot 2 | 769±27 | 389±12 | 679±56 | 249±4 | 907±57 | 279±6 | 834±46 | 223±9 | N/A | N/A |
| | | Airport | 433±45 | 181±7 | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A |

# Table 2. DN levels and SNR

| Area / Date | Product type | Targets | DN levels with 1 -σ error bound | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Pan-band | | Blue | | Green | | Red | | NIR | |
| | | | Bright | Dark | Bright | Dark | Bright | Dark | Bright | Dark | Bright | Dark |
| Brookings, May 1 2000 | Standard MTFC On | Tarps | 607±24 | 371±17 | 834 ±82 | 243 ±10 | 535 ±43 | 260 ±6 | 341±22 | 226±7 | 826±68 | 364±26 |
| | | Parking lot 1 | 710±29 | | 556±20 | | 730±32 | | 689±33 | | | |
| | | Parking lot 2 | | | | | | | | | | |
| Brookings, June 30, 2000 | Standard MTFC On | Tarps | 749±38 | 377±12 | 949 ±149 | 251±4 | 673±82 | 287±8 | 442±51 | 226±12 | 975±94 | 561±21 |
| | | Parking lots | 666±24 | | 547±26 | | 732±46 | | 687±48 | | | |
| Big Springs, March 26, 2000 | Standard MTFC On | 80º Elevation | 1404 ±10 | 256 ± 3 | | | | | | | | |

| Area / Date | Product type | Targets | Signal-to-Noise Ratio (SNR) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Pan-band | | Blue | | Green | | Red | | NIR | |
| | | | Bright | Dark | Bright | Dark | Bright | Dark | Bright | Dark | Bright | Dark |
| Brookings, May 1 2000 | Standard MTFC On | Tarps | 25 | 22 | 10 | 49 | 12 | 43 | 16 | 32 | 12 | 14 |
| | | Parking lot 1 | 24 | | 28 | | 23 | | 21 | | | |
| | | Parking lot 2 | | | | | | | | | | |
| Brookings, June 30, 2000 | Standard MTFC On | Parking lots | 28 | 31 | 21 | 63 | 16 | 36 | 14 | 19 | | 27 |
| Big Springs, March 26, 2000 | Standard MTFC On | 80º Elevation | 140 | 85 | | | | | | | | |
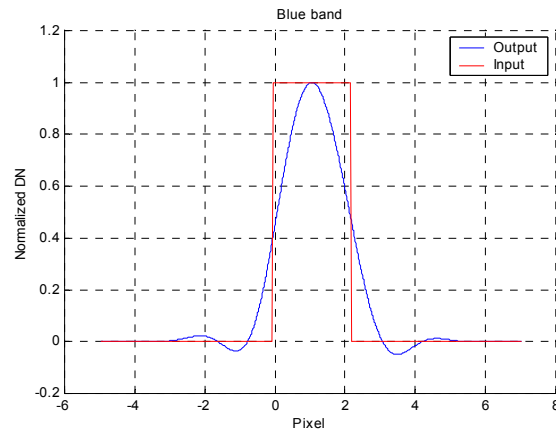
(a) Blue
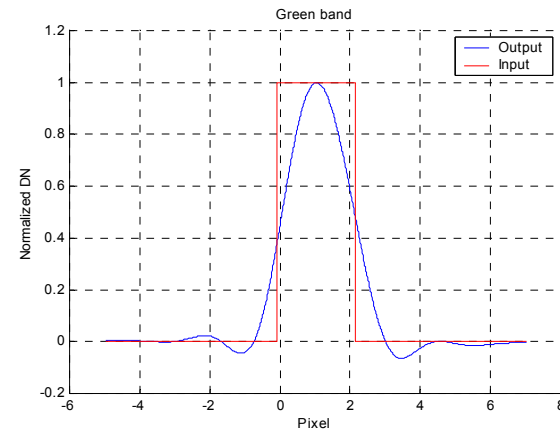
(b) Green
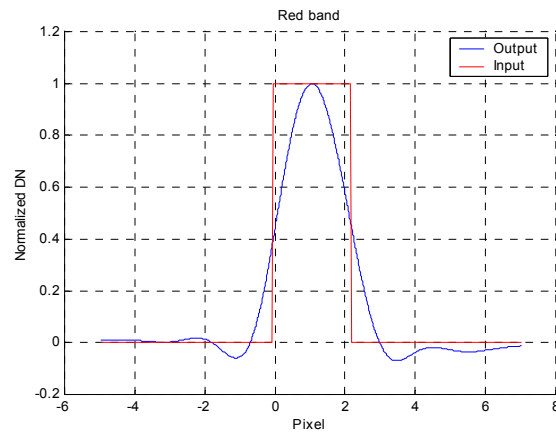
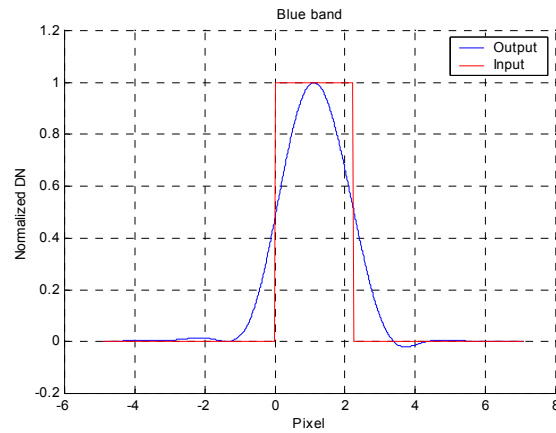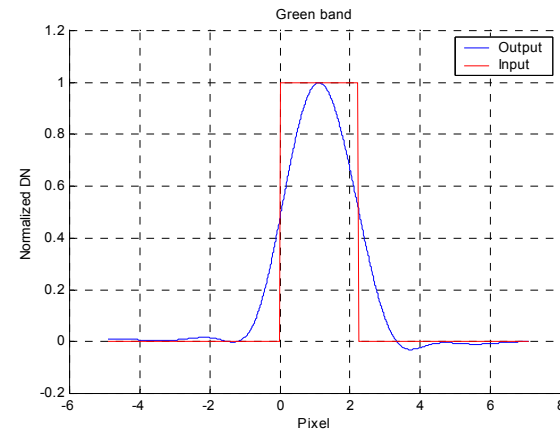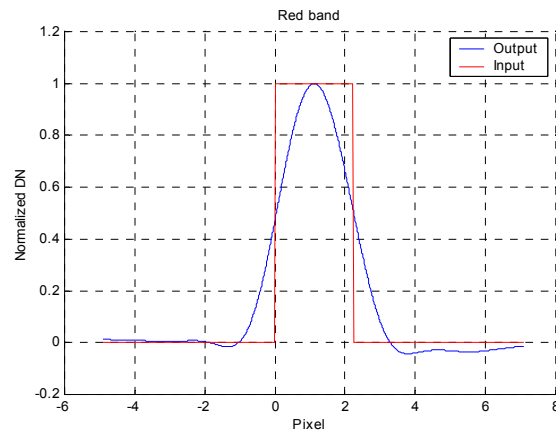(c) Red
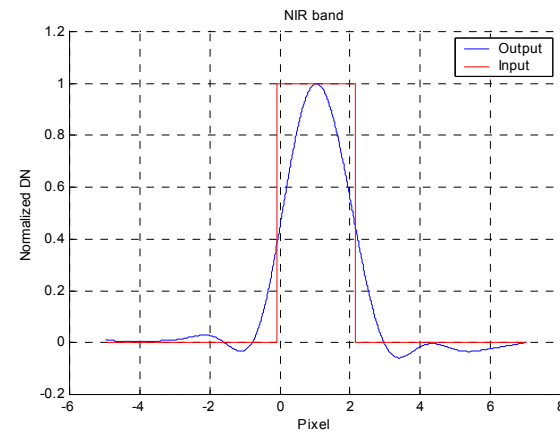
(d) NIR

Figure 19. Pulse response of tarps on June 30 2000 Brookings for <u>standard</u> product <u>with</u> MTFC.
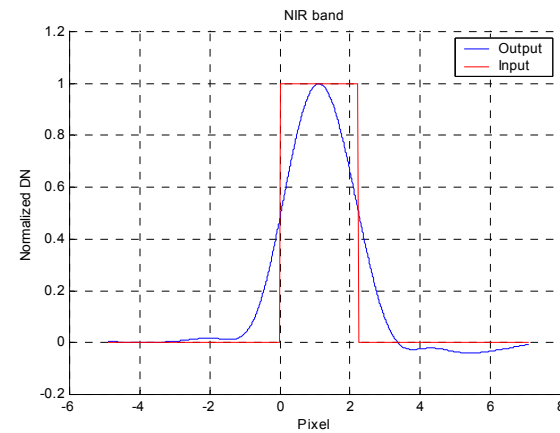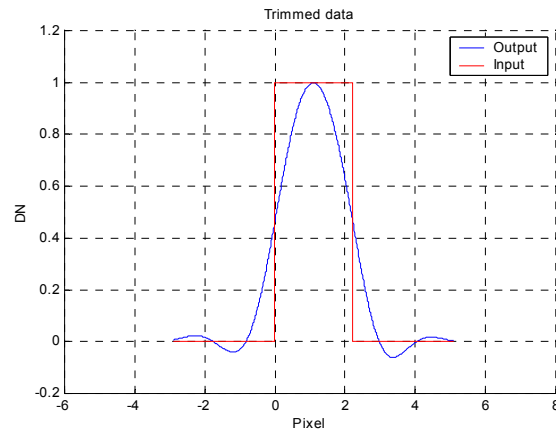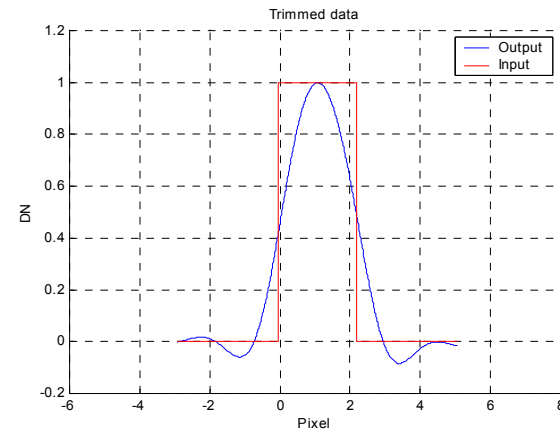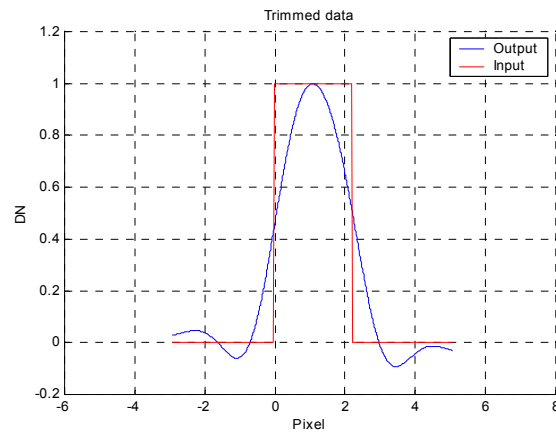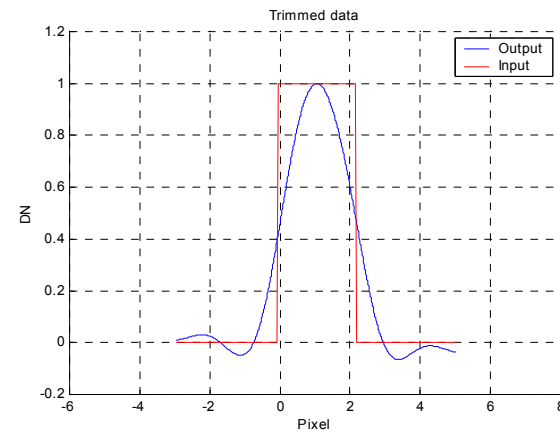
(a) Blue (b) Green

(c) Red (d) NIR

Figure 20. Pulse response of tarps on June 30 2000 Brookings for standard product without MTFC.
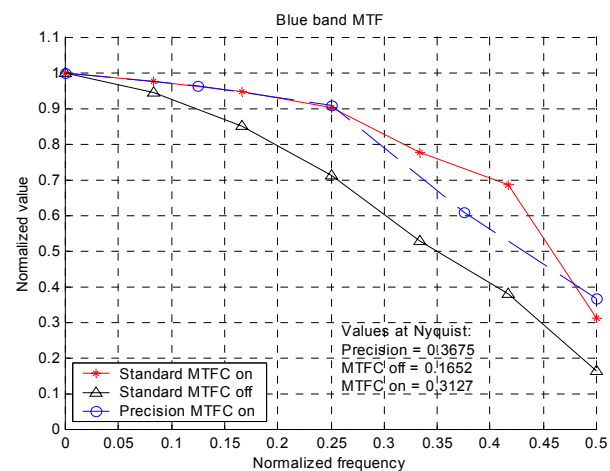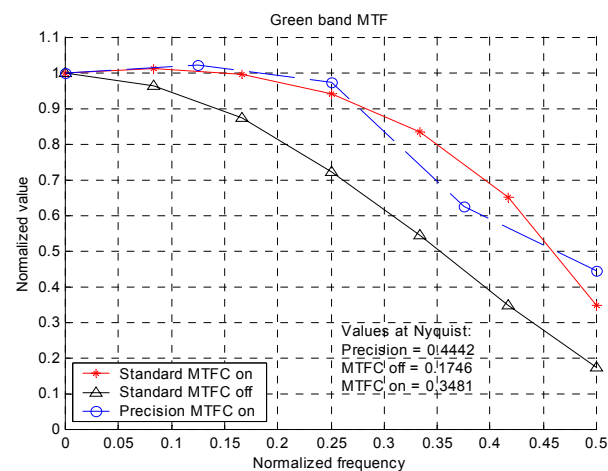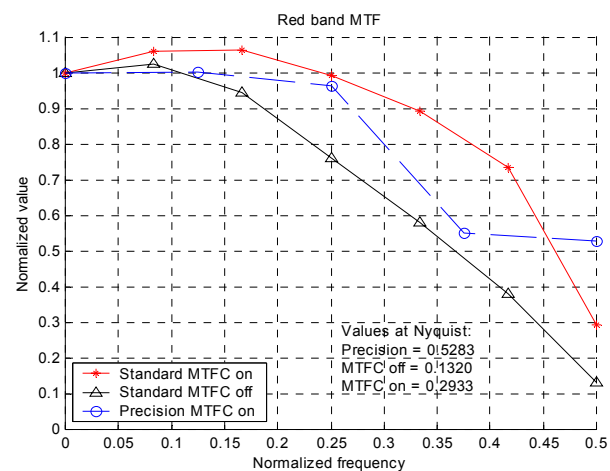
(a) Blue

(b) Green

(c) Red

(d) NIR

Figure 21. Pulse response of tarps on June 30 2000 Brookings for precision product with MTFC.
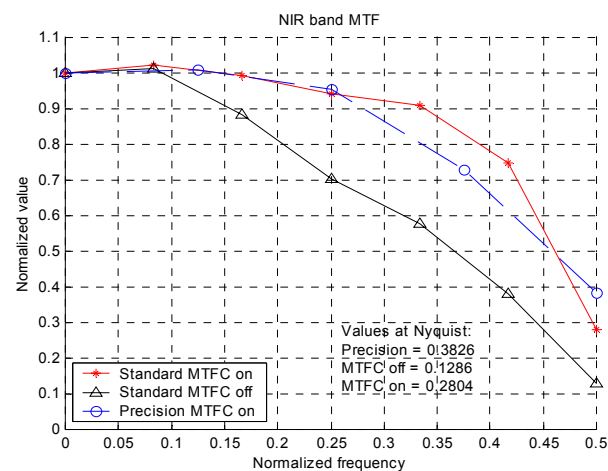
(a) Blue

(b) Green

(c) Red

(d) NIR

Figure 22. MTF of multispectral bands for tarps on June 30, Brookings

# Results (Cont.)

- Panchromatic band analysis
  - Standard products with/without MTFC on May 1 and June 30 were analyzed.
  - Precision product on June 30 was analyzed
  - Edge method was applied to parking lot 1 and 2.
  - Point Spread Functions (PSF) and MTF plots are shown in following Figures X5, X6.
  - FWHM values of all sites are shown in Table 1.
  - MTF values at Nyquist with 1-$\sigma$ error are shown in Table X.
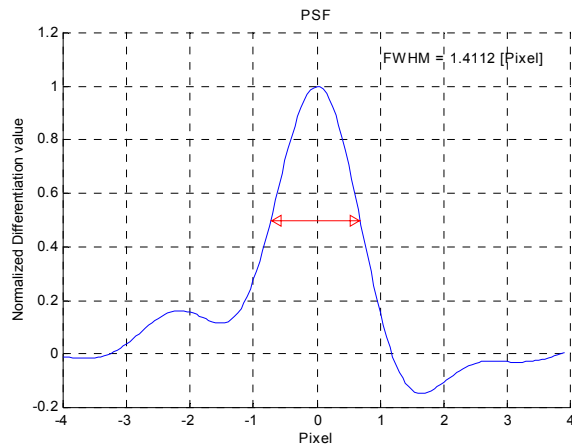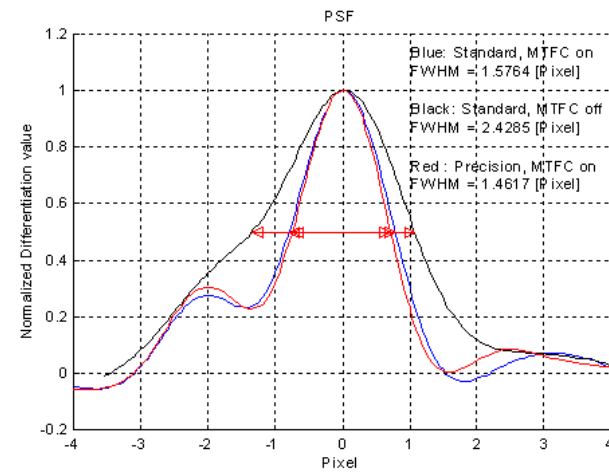
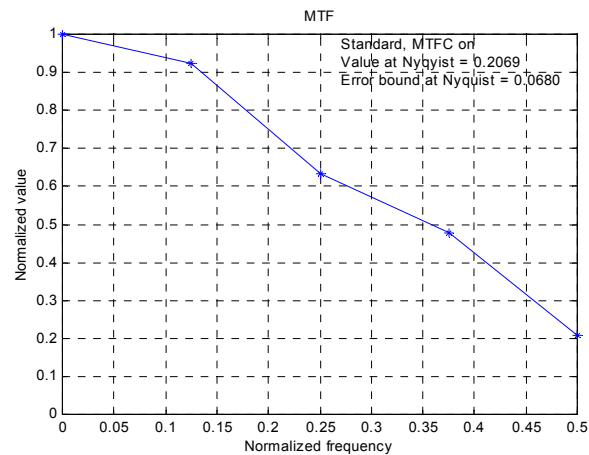(a) Parking lot 1, May
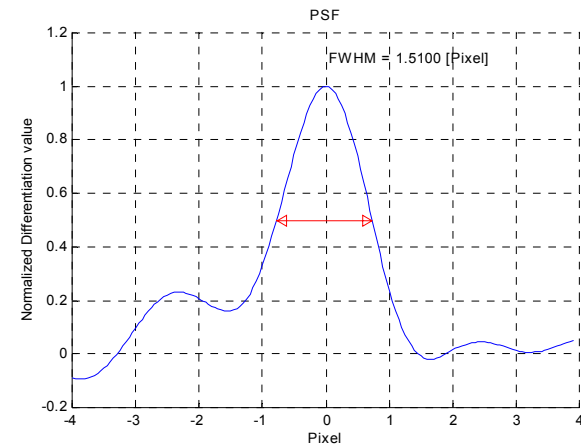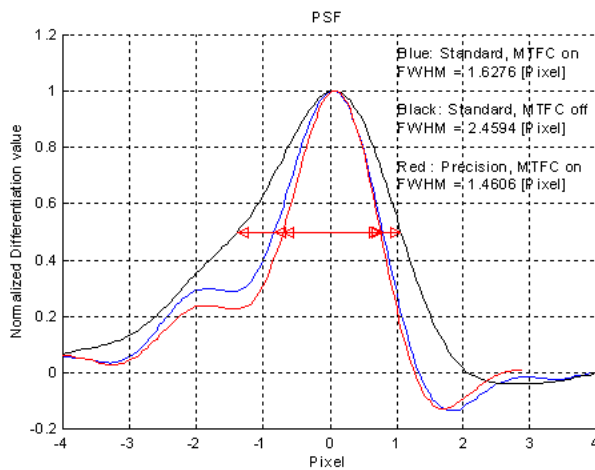
(b) Parking lot 2, May

(c) Parking lot 1, June

(d) Parking lot 2, June

Figure 23.  Pan-band PSF for parking lots

(a) Parking lot 1, May
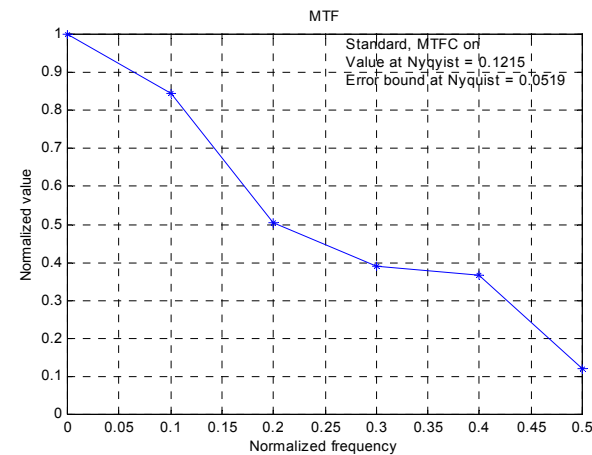
(b) Parking lot 2, May
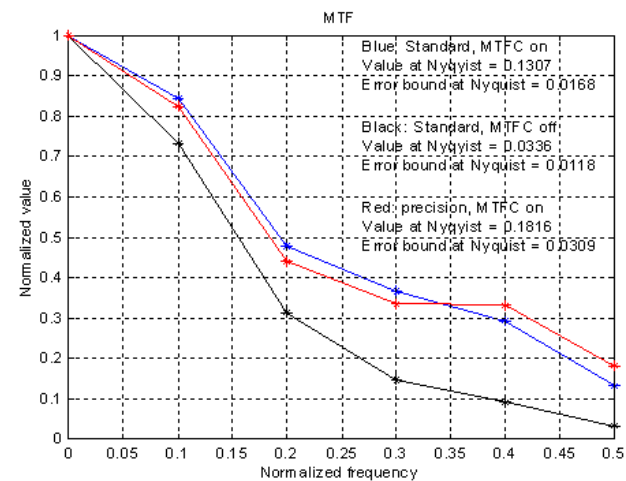
(c) Parking lot 1, June

(d) Parking lot 2, June
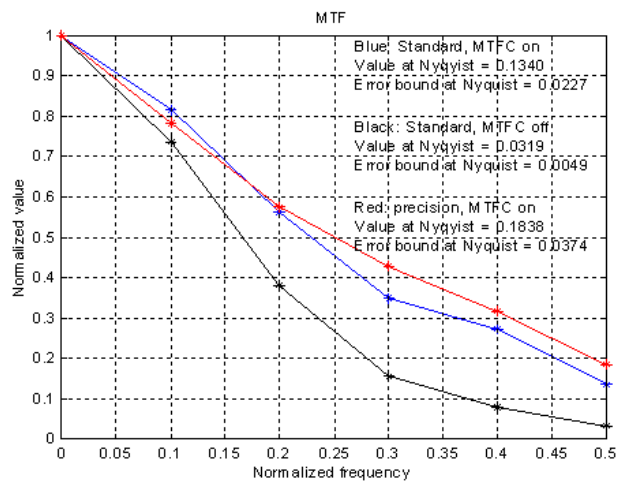
Figure 24. Pan-band MTF for parking lots

# Error Analysis



Figure 25. 1-σ error bound for standard product of parking lot 1 on June 30 2000
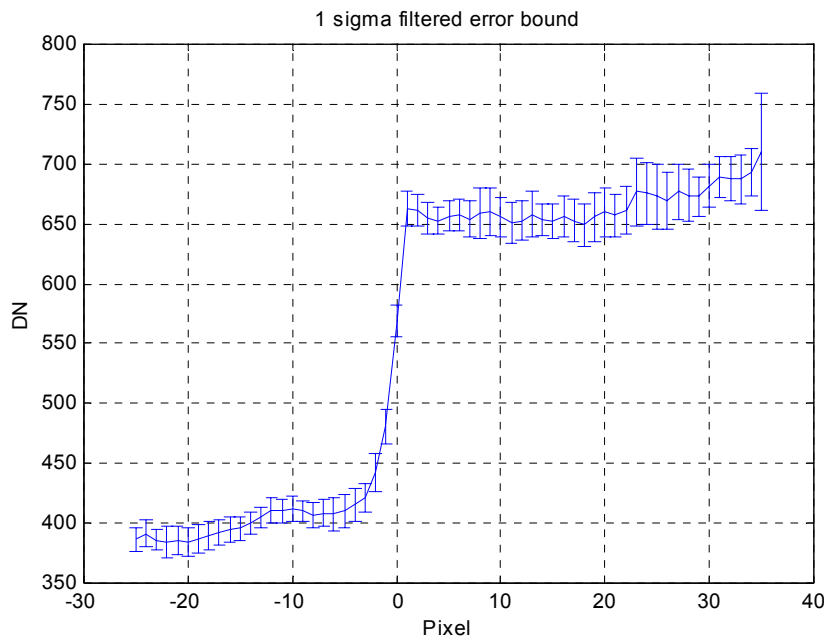
- 1-σ error bound was found in Figure 25.

- Error bound was filtered by a one pixel-width averaging filter to reduce the noise caused by differentiation.
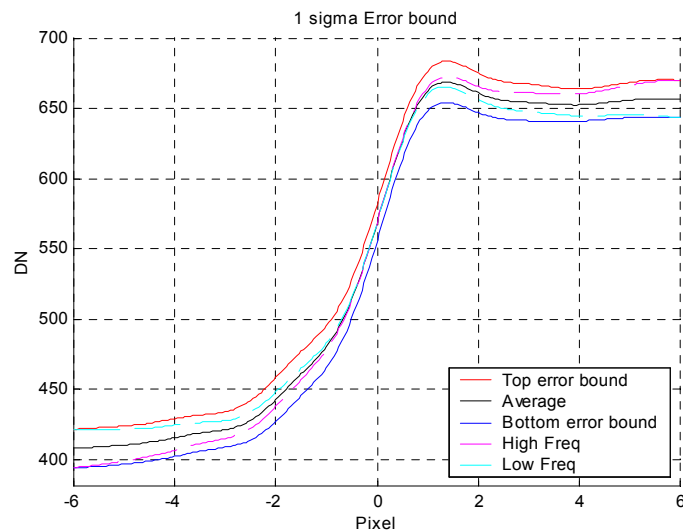
(a) Linear transition
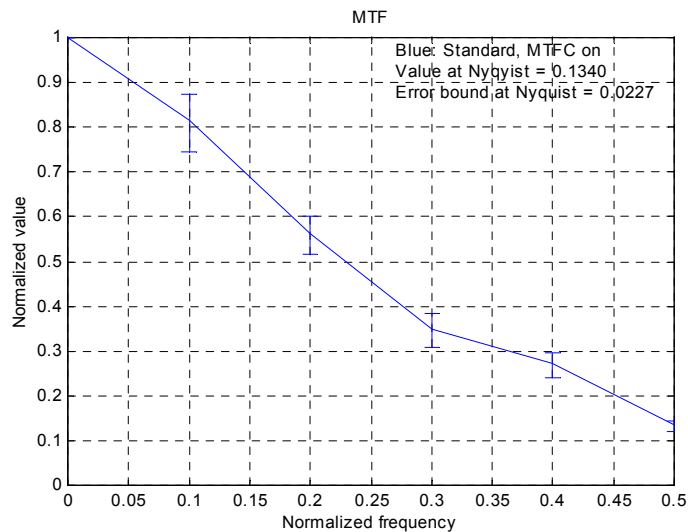


(b) MTF

- Finding worst and best possible MTF.
  - MTF plots from 1-σ top and bottom error bound were examined.
  - Linear transition between top and bottom of error bound was counted in Figure 26 as high and low frequency.

Figure 26. Linear transition in 1-σ error bound and MTF for standard product of parking lot 1 on June 30 2000

## Table 3. FWHM on Brookings scenes. FWHM values are only available with edge method.

| Area / Date | MTFC | Product type | Targets | FWHM [pixel] | | | |
|---|---|---|---|---|---|---|---|
| | | | | Pan-band | Blue | Green | Red |
| Brookings, May 1 2000 | On | Standard | Tarps | 1.66/1.78* | N/A | N/A | N/A |
| | | | Parking lot 1 | 1.41 | 1.31 | 1.30 | 1.31 |
| | | | Parking lot 2 | 1.51 | 1.68 | 1.67 | 1.66 |
| Brookings, June 30, 2000 | On | Standard | Tarps | 1.74 /1.52* | N/A | N/A | N/A |
| | | | Parking lot 1 | 1.62 | 1.18 | 1.17 | 1.14 |
| | | | Parking lot 2 | 1.57 | 1.10 | 1.08 | 1.06 |
| | Off | Standard | Tarps | 2.59/2.13* | N/A | N/A | N/A |
| | | | Parking lot 1 | 2.45 | 1.21 | 1.36 | 1.33 |
| | | | Parking lot 2 | 2.42 | 1.24 | 1.22 | 1.20 |
| | On | Precision | Tarps | 1.59/1.70* | N/A | N/A | N/A |
| | | | Parking lot 1 | 1.46 | 1.61 | 1.54 | 1.52 |
| | | | Parking lot 2 | 1.46 | 1.20 | 1.17 | 1.16 |

*Left edge / right edge

# Table 4. MTF values with (non-symmetric) 1-σ error bound on Brookings scenes.

| Area / Date | MTFC | Product type | Targets | MTF value at Nyquist frequency with 1-σ error bound | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | Pan-band | Blue | Green | Red | NIR |
| Brookings, May 1 2000 | On | Standard | Tarps | 0.09±0.02/ 0.03 ±0.00* | 0.10 ±0.11 | 0.18 ±0.07 | 0.25 ±0.26 | 0.17 ±0.10 |
| | | | Parking lot 1 | 0.20 ±0.03 | 0.28 ±0.01 | 0.28 ±0.02 | 0.27 ±0.02 | N/A |
| | | | Parking lot 2 | 0.12 ±0.06 | 0.03 ±0.02 | 0.06 ±0.02 | 0.07 ±0.01 | N/A |
| | | | Airport | 0.01 ±0.01 | N/A | N/A | N/A | N/A |
| Brookings, June 30, 2000 | On | Standard | Tarps | 0.10±0.02/ 0.09 ±0.01* | 0.29 ±0.02 | 0.35 ±0.07 | 0.35 ±0.12 | 0.30 ±0.08 |
| | | | Parking lot 1 | 0.13 ±0.01 | 0.43 ±0.02 | 0.44 ±0.01 | 0.49 ±0.02 | N/A |
| | | | Parking lot 2 | 0.13 ±0.01 | 0.57 ±0.06 | 0.60 ±0.05 | 0.68 ±0.07 | N/A |
| | | | Airport | 0.02 ±0.00 | N/A | N/A | N/A | N/A |
| | Off | Standard | Tarps | 0.02±0.01/ 0.02 ±0.00* | 0.15 ±0.02 | 0.20 ±0.06 | 0.20 ±0.10 | 0.17 ±0.08 |
| | | | Parking lot 1 | 0.03 ±0.00 | 0.34 ±0.01 | 0.22 ±0.00 | 0.24 ±0.01 | N/A |
| | | | Parking lot 2 | 0.03 ±0.01 | 0.29 ±0.03 | 0.32 ±0.02 | 0.34 ±0.03 | N/A |
| | | | Airport | 0.00 ±0.01 | N/A | N/A | N/A | N/A |
| | On | Precision | Tarps | 0.14±0.02/ 0.09 ±0.02* | 0.34 ±0.04 | 0.45 ±0.10 | 0.67±0.30 | 0.41 ±0.12 |
| | | | Parking lot 1 | 0.18 ±0.02 | 0.13 ±0.02 | 0.15 ±0.02 | 0.14 ±0.01 | N/A |
| | | | Parking lot 2 | 0.18 ±0.02 | 0.34 ±0.01 | 0.43 ±0.03 | 0.44 ±0.02 | N/A |
| | | | Airport | 0.01 ±0.01 | N/A | N/A | N/A | N/A |

*Left edge / right edge

## Table 5. MTF values with (non-symmetric) 1-σ error bound on Brookings scenes.

| Area / Date | MTF C | Product type | Targets | MTF value at Nyquist frequency with 1 -σ error bound | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | Pan-band | Blue | Green | Red | NIR |
| Brookings, May 1 2000 | On | Standard | Tarps | | | | | |
| | | | Parking lot 1 | 0.20 ±0.03 | | | | |
| | | | Parking lot 2 | 0.12 ±0.03 | | | | |
| | | | Airport | | | | | |
| Brookings, June 30, 2000 | On | Standard | Tarps | | 0.29 ±0.02 | 0.35 ±0.07 | 0.35 ±0.11 | 0.30 ±0.08 |
| | | | Parking lot 1 | 0.13 ±0.01 | | | | |
| | | | Parking lot 2 | 0.13 ±0.01 | | | | |
| | | | Airport | | | | | |
| | Off | Standard | Tarps | | 0.15 ±0.02 | 0.20 ±0.06 | 0.20 ±0.10 | 0.17 ±0.08 |
| | | | Parking lot 1 | 0.03 ±0.00 | | | | |
| | | | Parking lot 2 | 0.03 ±0.01 | | | | |
| | | | Airport | | | | | |
| | On | Precision | Tarps | | 0.34 ±0.04 | 0.45 ±0.10 | 0.67±0.30 | 0.41 ±0.12 |
| | | | Parking lot 1 | 0.18 ±0.02 | | | | |
| | | | Parking lot 2 | 0.18 ±0.02 | | | | |
| | | | Airport | | | | | |

# Results (Cont.)

- Big Springs, TX.
  - Panchromatic band analysis
    - Standard products with/without MTFC product were used with 60° and 80 ° elevation angle.
    - Edge method has been applied to the target.
    - Point Spread Functions (PSF) and MTF plots are shown in following Figures 28, 29.
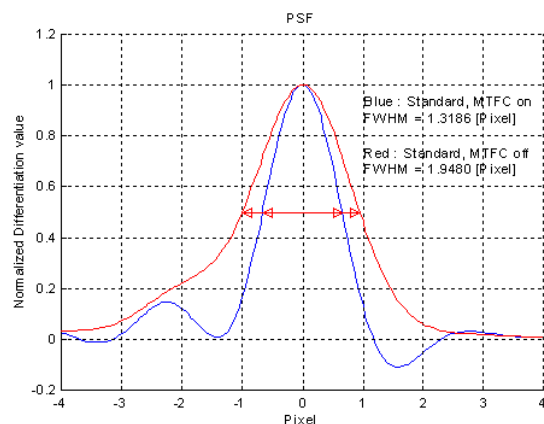    - Data acquired March 26, 2000.
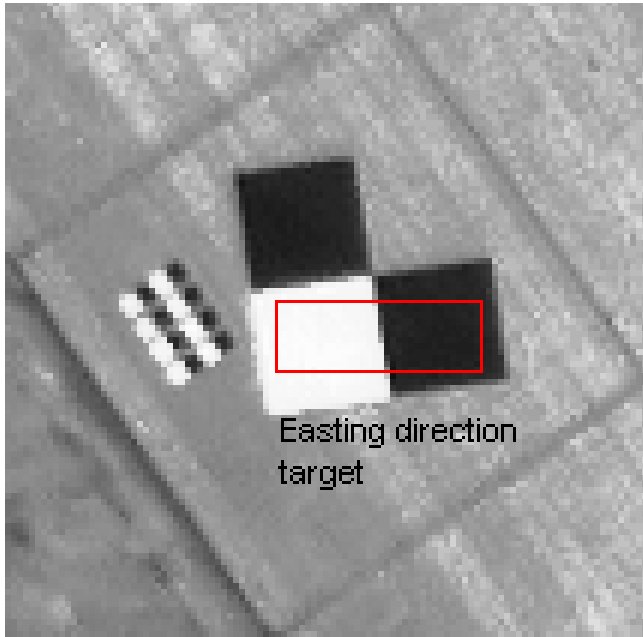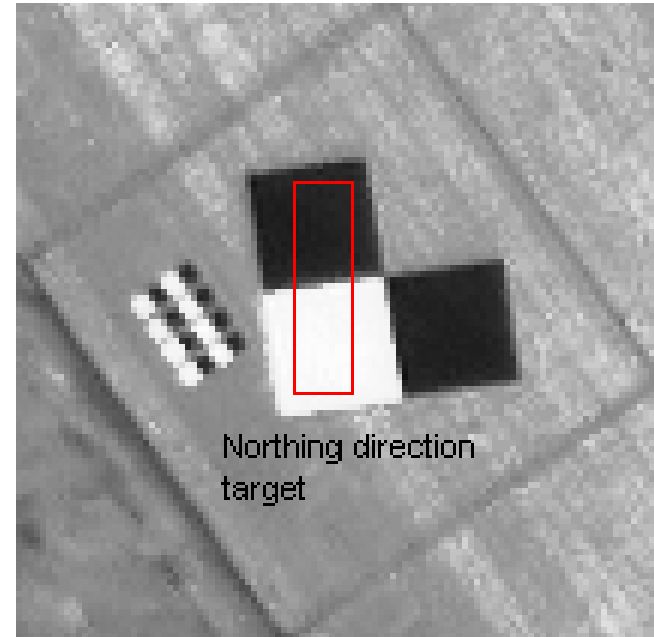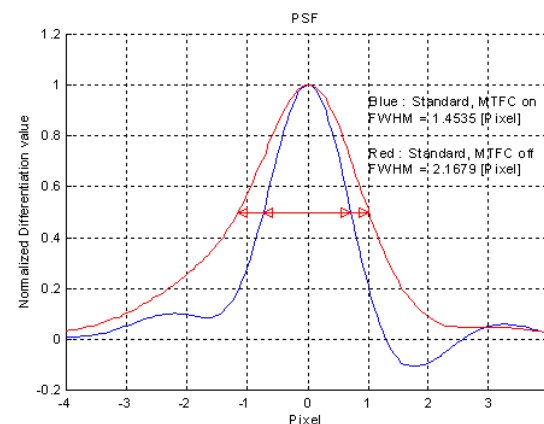
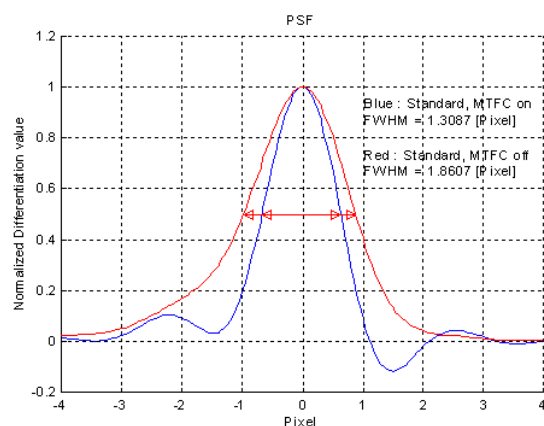(a) Easting direction target     (b) Northing direction target
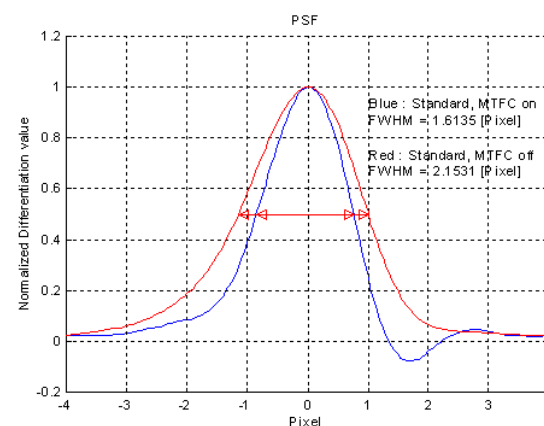
Figure 27. Big Springs target

(a) PSF with 60° El. angle in the Easting direction
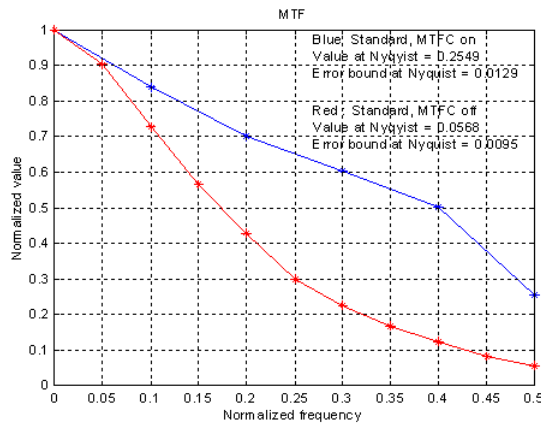
(b) PSF with 60° El. angle in the Northing direction

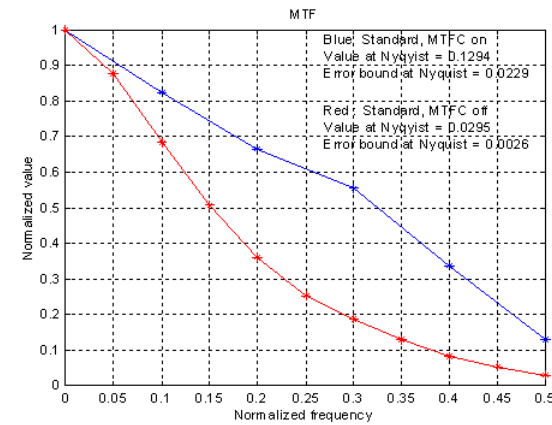(c) PSF with 80° El. angle in the Easting direction

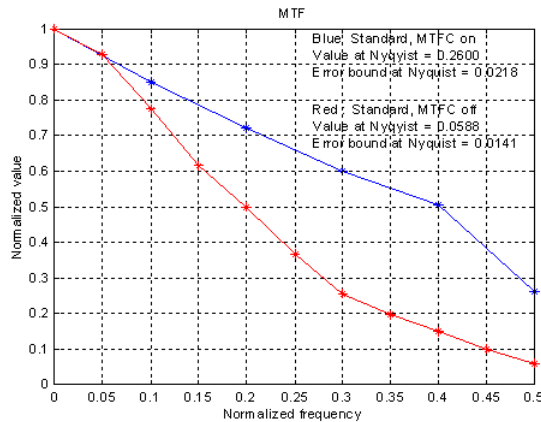(d) PSF with 80° El. angle in the Northing direction

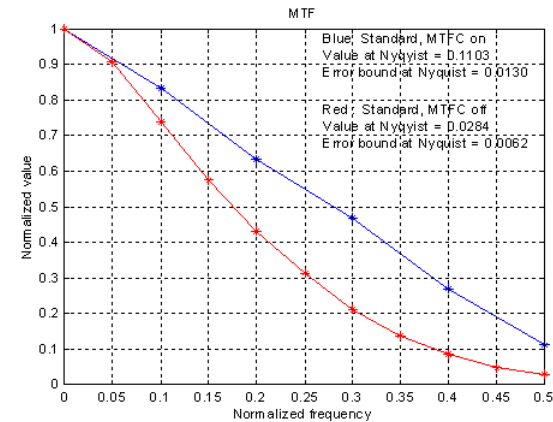Figure 28. Pan-band PSF for the Big Springs target.

(a) PSF with 60° El. angle in the
Easting direction



(b) PSF with 60° El. angle in the
Northing direction



(c) PSF with 80° El. angle in the
Easting direction



(d) PSF with 80° El. angle in the
Northing direction

Figure 29. Pan-band MTF for the Big Springs target.

# Table 6. FWHM values on Big Spring, TX

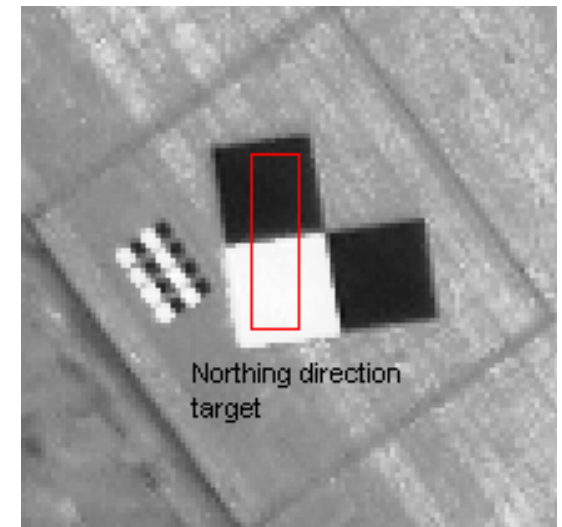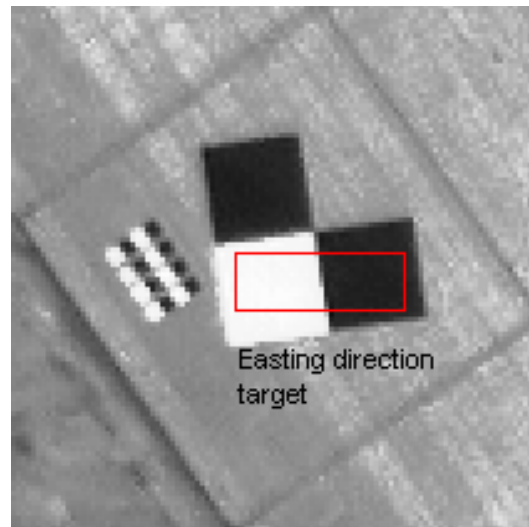| Area / Date | Elevation angle | MTFC | FWHM | |
|---|---|---|---|---|
| | | | Easting | Northing |
| Big Springs March, 26 2000 | 60.54 | On | 1.32 | 1.45 |
| | 60.54 | Off | 1.95 | 2.17 |
| | 80.61 | On | 1.31 | 1.61 |
| | 80.61 | Off | 1.86 | 2.15 |



Easting direction target

Northing direction target

## Table 7. MTF values with 1-σ error bound on Big Spring scenes

| Area / Date | Elevation angle | MTFC | MTF at Nyquist value with 1-σ error bound | |
|---|---|---|---|---|
| | | | Easting | Northing |
| Big Springs March, 26 2000 | 60.54 | On | 0.25 ± 0.01 | 0.13 ± 0.02 |
| | 60.54 | Off | 0.06 ± 0.01 | 0.03 ± 0.00 |
| | 80.61 | On | 0.26 ± 0.02 | 0.11 ± 0.01 |
| | 80.61 | Off | 0.06 ± 0.01 | 0.03 ± 0.00 |



Easting direction target
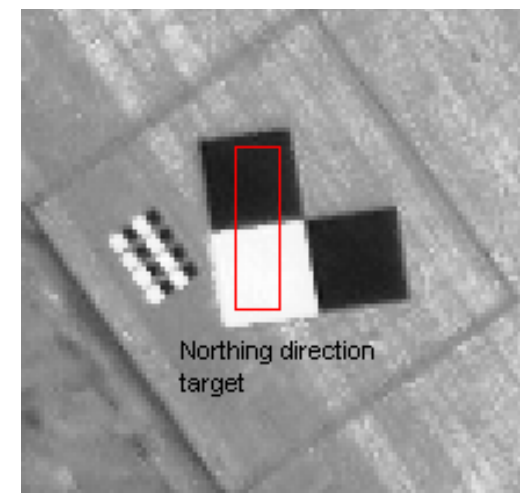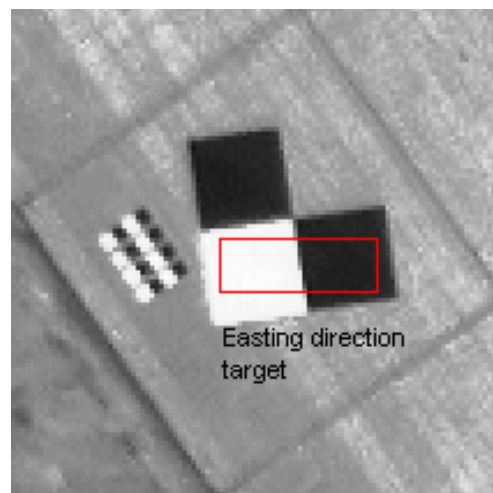
Northing direction target

Table 8. DN levels with 1-σ error bound on Big Spring scenes

| Area / Date | Elevation angle | MTFC | DN levels with 1-σ error bound | | | |
|---|---|---|---|---|---|---|
| | | | Easting | | Northing | |
| | | | Bright | Dark | Bright | Dark |
| Big Springs March, 26 2000 | 60.54 | On | 1279 ± 9 | 307 ±5 | 1280±9 | 311±7 |
| | 60.54 | Off | 1279±7 | 308±4 | 1279±6 | 311±6 |
| | 80.61 | On | 1404±10 | 256±6 | 1407±8 | 261±9 |
| | 80.61 | Off | 1404±8 | 255±3 | 1407±6 | 261±7 |

# Comparison of Big Springs and Brookings results

| FWHM | | |
|---|---|---|
| Panchromatic band, Standard Product | | |
| | MTFC Off | MTFC On |
| TX, March 26 <br> 80º Elevation | 1.86 | 1.31 |
| SD, May 1 | | 1.46 |
| SD, June 30 | 2.43 | 1.60 |
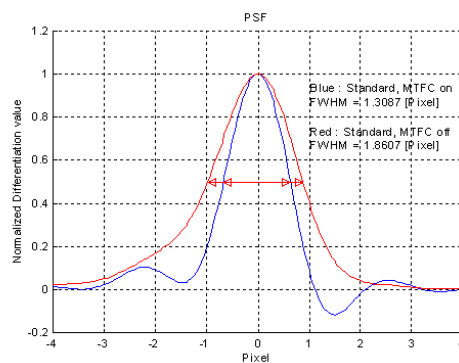


March, 2000
Big Springs
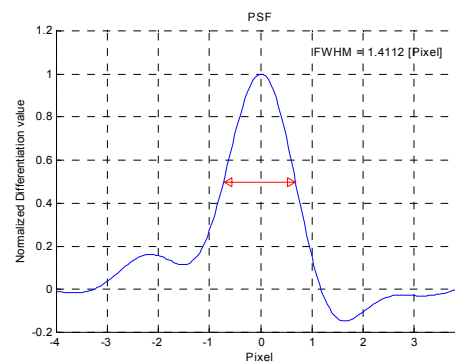
May, 2000
Brookings
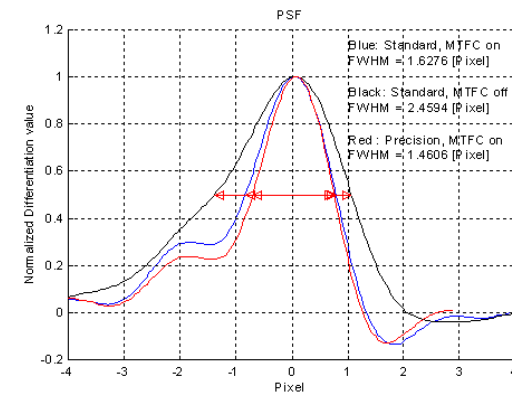
June, 2000
Brookings

# Final Thoughts

- IKONOS sensor appears to meet SDB spec!
  - Multispectral MTF @ Nyquist > 0.29, (Spec > 0.23)
  - Panchromatic MTF @ Nyquist > 0.13, (Spec > 0.10)
- MTFC correction more pronounced in Pan band
  - Ringing effect observed in Pan and MS bands
- Precision product tends to enhance MTF over standard product.
  - FWHM reduced in Pan but increased in MS bands.
- Possible degradation in MTF of Pan band

# Final Thoughts (con't.)



- **Tarp-based target works well**
  - Physical layout extremely important
  - Specular reflectance apparent in Pan band
- **Targets of opportunity can produce good results**
  - Orientation is critical
  - Parking lot edges worked well for Pan band
  - Runway centerline results TBD
- **Big Springs target is excellent for Pan band characterization**
  - Recommend maintaining the site.